Gaining on the Decibel

Part 1: Would you say the bel, like the henry and the farad, is a unit of measure? If you answered yes (or if you answered no), you must read this article.

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If Alexander Graham Bell were alive today, he'd be turning over in his grave. And not only because we hams are forever taking his name in vain. After all, how would you feel if your life's work went largely ignored for over a hundred years, and instead you achieved fame for something which happened almost accidentally?

I am referring, of course, to this business of the telephone. Professor Bell, it seems, was first and foremost a teacher of the deaf. His greatest gift was training other teachers in helping the hearing impaired to function in a society of sounds. In fact, years after his now-famous invention, he told family members that it was really for his work with the deaf that he wanted to be remembered. Things seldom work out according to plan.

How exactly did the telephone come about? It's evident that Bell was trying to develop a device to amplify human speech. In a sense, he succeeded. Although Dr. Lee DeForest's audion tube (circa 1907) is most likely the first all-electronic amplifier, "the carbon microphone of telephony is an electromechanical amplifier, whose electrical power output can be a thousand times greater than its mechanical voice-power input."[1]

Dr. Bell realized that the human ear, like the "guess meter" of your favorite short-wave receiver, responds logarithmically to its input stimulus. And this logarithmic relationship, quantified by Bell and other early acoustical experimenters, has given us our standard tool for describing the behavior of nearly all electronic communications systems.

Reviewing Logarithms

The logarithm of a number is simply the power to which a specific base (or radix) must be raised to equal that number. The two most familiar bases are ten (the base of so-called *common* logarithms), and *e*, which represents the base of the *Napierian*, or *natural*, system of logarithms.[2] In this paper, with but a single exception (which I will clearly identify), we will be dealing exclusively with the radix 10. For example, since the number 1000 can be expressed as the radix 10 raised to the power three (10^3), we can say that the common logarithm of 1000 is 3. Simple, isn't it?

One advantage of logarithms is that they reduce rather cumbersome numbers to manageable proportions. Another is that their use reduces multiplication and division problems (always a challenge for me) to simple addition and subtraction (which even I can handle). But logarithmic response, be it of the ear or the calibrated meter, means that a large change in the applied stimulus results in a significantly smaller change in the output parameter, or response.

Because the ear responds logarithmically to applied acoustical power, a logarithmic unit, the bel (after Alexander Graham), can be used to express *changes* in power, or power *ratios*. Mathematically,

$$\text{bel} = \log_{10}(\text{Ap}) \qquad \text{(Eq 1)}$$

where

$\log_{10}$ represents the common (base 10) logarithm
(Ap) represents a given power ratio

I must emphasize this is the *only* meaningful definition of the bel, and any attempt to apply the term to anything other than power ratios will get you into trouble. A recent article by Gruchalla did an excellent job of clarifying the reasons for such rigid standardization.[3] I won't repeat that presentation here, but highly recommend Gruchalla's paper to anyone interested in applying what comes next, the decibel. Go read it now!

Introducing the Decibel

Done reading? Good. Now the bel, like the farad, the henry, the ampere and the watt, is a basic unit of respectable magnitude, one which we might care to subdivide. The Greek alphabet provides us with ample prefixes to indicate subdivision of a quantity, and we can apply these to the bel to increase our resolution without going too far to the right of the decimal point. The millibel (mB), microbel (μB), nanobel (nB), picobel (pB), femtobel (fB) and tacobel (tB) are all viable designations for thousandth, millionth, billionth, trillionth, quadrillionth of a bel, and lunchtime, respectively.

Of course, you might argue that millibel sings on the Grand Ole Opry, and a microbel relays many multiplexed telephone signals at extremely short wavelength. Fig 1 depicts a typical μB relay station.

The most convenient subdivision of the bel for our purposes, one that affords us ample resolution for electronic applications, is simply the 10th of a bel. The Greek prefix for 10th is deci, hence the unit decibel, or dB.

Since there are 10 decibels in each bel, we can expand Eq 1:

$$(\text{number of dB}) = 10 \times (\text{number of bels})$$

or

$$\text{dB} = 10 \times (\log_{10}\text{Ap}) \qquad \text{(Eq 2)}$$

which is the fundamental, and only valid, definition of the decibel. Easy as falling off a log!

Capitalization

Ever notice how we abbreviate everything in electronics and that there are

[1]Notes appear on page 22.

only 26 letters in the alphabet? Fortunately, the Greek alphabet affords us a few more characters, but sooner or later we're bound to run out of unique literals with which to define a quantity unambiguously. One way out of the dilemma is through the use of capitalization. For example, what's the difference between an mB and an MB? The former obviously represents millibel (lower case m), a very small unit. MB, on the other hand, starting with a capital M, most likely stands for Ma Bell, a very large unit to be sure, which is why the government had to break it up.[4]

Capitalization standards are no less important when we get to the decibel. The abbreviation for bel, being derived from a proper noun, should of course be capitalized. And remember that deci, a tenth, is a *small* prefix and thus should be written lower case. That gives us dB, but certainly *not* DB (which would mean Decabel, 10 bels, which differs from what we intend by a factor of only a hundred). And most emphatically not Db, which stands for Dumbbel!

The Voltage Decibel

This next problem will be solved using Ohm's law, so you might want to go back and review first. Ready?

Consider an electromotive force (voltage) applied across a *fixed and unchanging* resistance. If the applied potential is increased by, say, a factor of two, what change, if any, will occur to the resulting kinetic energy, or current? If you said the current will double, give yourself an A for the day.

Now the hard part. What change, if any, occurred to the total *power* dissipated in our resistor? Since potential energy (measured in volts) and kinetic energy (measured in amperes) both doubled, and since power is the product of potential and kinetic energy, power gain was the product of voltage gain and current gain, or four.

In our example, the voltage gain and current gain were the same. This occurs only in fixed-resistance (or more generally, fixed-impedance) cases. But when (and only when) the impedance across which we are measuring is *constant*, we can develop the following relationships:

$$Ap = Av \times Ai$$

where Ap, Av and Ai represent power, voltage and current ratios (or gains), respectively. Now, since in our special case

$$Av = Ai$$

we can combine the two above equations. Thus

$$Ap = Av \times Av = Av^2 \qquad \text{(Eq 3)}$$

or

$$Ap = Ai \times Ai = Ai^2 \qquad \text{(Eq 4)}$$

These relationships hold only if Av and Ai are equal. And when does that occur? *Only* in a constant-impedance system.

You may have seen in textbooks an equation that looks something like this:

$$dB = 20 \log_{10} (Av)$$

Perhaps, from the preceding discussion, you can guess where it came from. In a constant-impedance, or matched-impedance situation, since $Ap = Av^2$, you could combine Eqs 2 and 4, thus:

$$dB = 10 \log_{10} (Av)^2$$

This can be simplified by recalling that a logarithm is simply an exponent. Therefore

$$\log (A^X) = x \log (A)$$

By moving the exponent out front, we get

$$dB = 2 \times 10 \log_{10} (Av)$$

which becomes

$$dB = 20 \log_{10} (Av)$$

Please notice that the foregoing works only when impedances are constant and is a *derivation*, not a definition, of dB.

Introducing the Neper

We have established that when impedance is constant, voltage ratio and current ratio are equal. We now come to the exception I mentioned earlier, in which we will be dealing with logarithms to a base other than 10.

The Neper (a misspelling of Napier) is a convenient way of expressing voltage or current ratios logarithmically. It is defined as

$$N = \log_e (Av) \qquad \text{(Eq 5)}$$

or

$$N = \log_e (Ai) \qquad \text{(Eq 6)}$$

There are two noteworthy points in these relationships. One is that, unlike the bel, the Neper is based on natural, or Napierian, logarithms, which certainly seems appropriate. The other is that the Neper is defined in terms of either voltage ratio or current ratio. Obviously, this makes sense only if the two ratios are the same, and that happens only when impedance is constant. So a significant constraint on Nepers is that there are indeed both "voltage" Nepers and "current" Nepers, but they bear a meaningful relationship one to the other *only* in an impedance-matched system. The dB, on the other hand, is *defined* only for an impedance-matched system!

Now that we have two logarithmic units to choose from, we can establish some operating guidelines. When dealing with voltage ratios or current ratios, use the Neper when a logarithmic unit is required. If it is power ratio you're interested in, use the decibel. And in either case, apply the units across a fixed and constant impedance. These constraints will prevent the confusion which often results from trying to use power Nepers, or voltage dB.

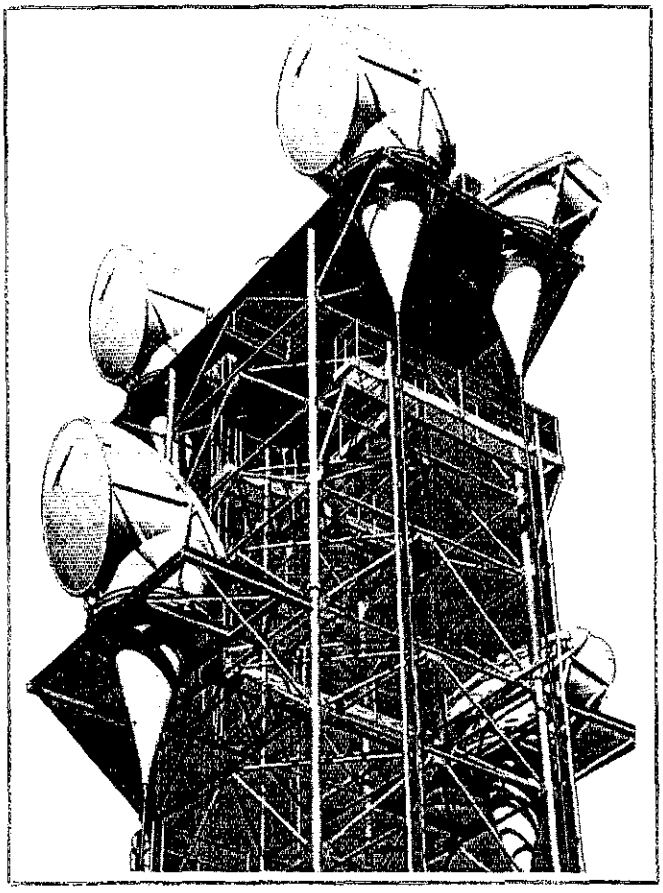

Fig 1—Antenna tower, the most visible element of a μB relay station (see text).

What's Wrong with Voltage Decibels?

Is there *something wrong* with using voltage dB? Plenty. It tends to imply that the dB

numbers for power and voltage are somehow different (they use different equations, don't they?). And that, in turn, leads to the most common mistakes people make with dB, the ones Gruchalla relates. See note 3.

Let's consider our previous example, in which we doubled the potential energy applied across a fixed resistance. By squaring the quantity (twice the voltage) and multiplying its common logarithm by 10, we find that doubling voltage results in a gain of 6 dB. You will recall that the current also doubled, so we can square the quantity (twice the current), take 10 times its log, and conclude that doubling current results in a gain of 6 dB.

The problem starts when we try to compute power gain. Power gain is clearly voltage gain times current gain, and didn't we say that you can multiply two numbers by adding their logarithms? Well, 6 dB plus 6 dB (related to the log of voltage gain and current gain, respectively, remember?) implies a power gain of ... 12 dB!

The fallacy in this is that there *is* no such thing as "voltage dB" or "current dB." The decibel is a logarithmic expression of power ratio *only*. The two 6-dB figures we got, by squaring voltage ratio and current ratio, are *both* actually power gains (because that, by definition, is what decibels are).

Back in the early days of my career, I lost a consulting job over that one. My client had characterized a filter I was going to incorporate into a receiver I was designing, and my task was to design in enough gain to overcome its insertion loss. Recalling the different "dB formulas" I had been taught in school, I asked my employer, "Is that 8 dB voltage or 8 dB power loss?" He didn't renew my contract, and I knew then that someday I'd have to write this article.

Absolute vs Relative Power

Since dB expresses a power ratio, or change in power, it is a relative measure. But if we use dB to compare a particular power level to a *specified* reference power, an absolute measure results. The most widely accepted standard power levels for comparison are the milliwatt or, for high-power transmitter applications, the watt. A logarithmic expression of any power level, as it compares to the reference levels 1 milliwatt and 1 watt, would be written in dBm (decibels compared to a milliwatt) and dBW (decibels compared to a watt), respectively.

Inadvertent mixing of "dB" with "dBm" can produce some interesting results. For example, you can increase your transmitter power by a certain number of dB, or dBm, and either can be correct, depending on your intentions. Increasing power 3 dB will double your output, whereas increasing power by 3 dB*m* adds an additional 2 *milliwatts* to your signal. Are the two equivalent? Only if your transmitter was putting out 2 milliwatts to begin with!

In this part of the article we have traced the history of the decibel, or dB, and introduced some standards for its proper use. In Part 2, we will explore a number of applications of the dB to electronic communications in general, and ham radio in particular. Until then, I invite you to reflect on the advice of John Donne, "... and therefore never send to know for whom the bel tolls; it tolls for Power."

Notes

[1]Dr. Robert A. Chipman, *Transmission Lines* (New York: McGraw-Hill Book Co, 1968), p 5.

[2]After John Napier, Laird of Merchinston, the Scottish mathematician who published the first system of logarithms in 1614.

[3]Michael Gruchalla, "Defining the Decibel," *Ham Radio*, Feb 1985, p 51.

[4]Small letter, small unit seems to work for everything except kilo, which for some unknown reason is properly abbreviated with a lower case k.

An Extra Class ham first licensed in 1961, Paul has the distinction of being one of the few hams in the world to be operational in all 18 ham bands from 1.8 MHz to 10 GHz. His main interest is microwaves, and his nearly three dozen articles on circuit design and construction have appeared extensively in 73, Ham Radio, Microwaves, Microwave Systems News, *the* Radio Handbook *and* IEEE Transactions on Microwave Theory and Techniques *during the past 10 years. Paul has operated moonbounce, meteor scatter, sporadic E and tropo scatter, as well as all the ham satellites since OSCAR 6. He frequently leads his division in ARRL VHF and UHF contests.*

Paul currently serves on the board of directors of Project OSCAR Inc, as an Assistant Director of the ARRL and as a member of the League's VHF/UHF Advisory Committee. He has been a featured technical speaker at numerous West Coast and Central States VHF Conferences, the IEEE International Microwave Symposium, WESCON, the first three Satellite Private Terminal Seminars and various ARRL Division and national conventions.

Professionally, Paul is an aerospace engineer and educator. He currently heads the Microwave Technology program at San Jose City College and serves as Professor of Aeronautics at San Jose State University. His consulting engineering activities have included the design of biomedical telemetry systems, satellite remote sensing equipment and the world's first commercial home satellite TV receiver.

Paul's chief nonelectronics interest is aviation. He is a commercial pilot and flight instructor, and was founding chairman of the Santa Clara County Airport Commission. He is listed in Who's Who in Aviation and Aerospace, *and* Who's Who in California.

Strays

I would like to get in touch with...

☐ anyone with information or suggestions to help me convert a Drake L4B linear amplifier for operation on the 160-m band. James Garls, W9SKO, 824 Henrietta St, Pekin, IL 61554.

☐ anyone with a manual/full-size schematic for a Hallicrafter SX-42 receiver. Will George, W4LHJ, 1731 Country Club Dr, Tullahoma, TN 37388.

☐ any hams interested in tuning into the AACS Alumni Net, which meets at 2200Z Fridays on 14,287. Jules Wenglare, W6YO, 1416 7th Ave, Delano, CA 93215, tel 805-725-8707.

☐ other Amateur Radio real-estate brokers who have had experience in dealing with antenna location restrictions. Bob Crockett, W1LF, 2 Ripley La, Weston, MA 02193.

☐ anyone with information on the Clegg FM 28. Tom Popovic, KI3R, 1008 Monroe, McKeesport, PA 15133.

☐ anyone with information on using the Macintosh computer on RTTY and AMTOR. Robert A. Winters, KD7P, 5633 123rd Ave, SE, Snohomish, WA 98290.

☐ anyone with a manual or schematics for a DuMont 304A oscilloscope or information on its filament current regulator. Arthur Katz, W2NJW, 7804 Haymarket La, Raleigh, NC 27609.

☐ anyone with a schematic or manual for a Bendix TA12 G aircraft transmitter. Dick Moore, VE3LRB, 235 Epworth Ave, London, ON N6A 2M2.

Gaining on the Decibel

Part 2: Money is power, and the decibel is an expression of a power ratio. Wouldn't you like to receive a 3-dB increase in spending money?†

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In the first part of this article we introduced the decibel, a logarithmic expression of *power* ratio, and demonstrated why it is inappropriate to apply this measurement tool directly to changes in EMF or current. We also presented standards for the proper capitalization of dB and explained how it can be used to express either absolute or relative power. You may wish to review the previous part before reading further.

In this part we will explore various applications, both proper and improper, of the dB to electronic communications in general and Amateur Radio in particular.

Antenna Gain

Most of us have considerable difficulty in visualizing how an antenna can have gain. Being a passive device, there's just no way an antenna with an applied input of 100 watts can possibly put out anything greater than 100 watts! The whole idea of antenna gain relates to the fact that the same 100-watt transmitter can deliver varying amounts of power *in a specified direction*, when connected to different antennas. Similarly, a receiver of specified sensitivity may recover widely varying signal-to-noise ratios, from a specific distant station *in a certain direction*, when fed with different antennas.

If you get the impression that antenna gain involves the performance of a particular antenna as compared to that of a specified reference antenna, you're absolutely right! The problems start in trying to specify the appropriate reference antenna.

A popular reference antenna for theoretical evaluations is the isotropic radiator, the only truly omnidirectional antenna. (Remember, "omnidirectional" means that the antenna radiates equally poorly in all directions.) An isotropic antenna connected to a transmitter disperses the radiant energy in a perfectly uniform sphere. An isotropic receiving antenna will similarly respond uniformly to applied signals from any direction in three-dimensional spherical space.

The only problem with referencing the performance of any physical antenna to that of an isotropic radiator is that the perfect isotrope doesn't really exist. You cannot build one, buy one or observe one in nature. Nothing is that uniform.[6]

An antenna whose radiation pattern is *nearly* uniform, in *most* directions, is the half-wave dipole. Simple to visualize and easy to implement, the half-wave dipole radiates a fairly uniform pattern in all directions except off its ends, where deep nulls appear. Does a dipole have gain, relative to an isotrope? Yes! All of the power fed to a properly matched dipole system must be radiated. And since there are nulls off the ends, the energy that would have gone into those nulls, if the dipole were an isotrope, has to go in some other direction. In actual fact, it adds to the power radiated *broadside* to the dipole, making its familiar "doughnut" radiation pattern a little fatter. Redirecting the energy from the nulls makes the signal available from a dipole, in the direction of its maximum radiation (broadside), about 2 dB greater than that from an isotrope.

Knowing the above, we now have a way of determining an antenna's gain, relative to an isotropic radiator, even though we do not have an isotropic reference antenna lying around the shack. Simply compare the signal power received from a distant station with the antenna under test to that received from the *same* station with a dipole.[7] The resulting power ratio can be converted to dB just as you've always converted power ratios to dB, by calculating 10 times its common log. The resulting figure is antenna gain in dB *relative to a dipole*, or dBd. Since you know the relationship between a dipole and an isotrope, you can now find antenna gain in dBi (decibels relative to an isotropic reference) simply by adding 2 dB to dBd.

The most common mistake made in antenna-gain measurements is that of not specifying the reference to which the antenna under test was physically or mathematically compared. An antenna gain of +10 dBi means something very different from a gain of +10 dBd. And an antenna gain expressed simply as +10 dB means something else again. It means the person specifying the gain was either trying to mislead and deceive, or he simply doesn't understand dB!

Free-Space Path Loss

Even before Congress passed the Inverse Square Law, it was well known that S-meter readings vary inversely with the distance to the DX station. To understand the relationship between distance and attenuation, we need to consider two points (A and B) of a communications path, separated by distance D and communicating via electromagnetic waves of wavelength λ. And to remove from the analysis the effects of antenna gain, beamwidth, radiation pattern or effective aperture, we will assume that both the transmitter (at Point A) and the receiver (at Point B) are connected to perfectly matched, ideal, lossless isotropic antennas.

As long as the distance D is great relative to the wavelength λ (the far-field restriction mentioned in Ref 7), it can be shown that the EMF recovered by the receiving antenna is a fraction of the EMF applied

†Part 1 appears in Feb 1986 *QST*. Part 3, the conclusion, will appear in a subsequent issue.

[6]Notes and references appear on page 31.

to the transmitting antenna, which varies with the ratio λ over D. The equality is:

$$Av = \frac{\lambda}{4\pi D}$$

where

Av is the voltage ratio $\frac{\text{(V received)}}{\text{(V transmitted)}}$

and the constant 4π comes to us from spherical trigonometry, representing the number of steradians in a sphere.

Of course, since Av is a unitless ratio (volts over volts cancels), it is important that λ and D be expressed in the same units.

Since we defined our antennas as being ideal, they are perfectly matched to free space. Thus, the potentials transmitted and received are measured across the same impedance, and power ratio becomes the square of potential ratio. We can therefore say

$$Ap = Av^2 = \left(\frac{\lambda}{4\pi D}\right)^2$$

And we know how to convert power ratios to dB:

$$dB = 10 \log Ap$$
$$= 10 \log \left(\frac{\lambda}{4\pi D}\right)^2$$

This yields a *negative* number, since path gain is less than unity. If we change the sign, it follows that free-space path *loss* α (the Greek letter alpha, lower case) would be:

$$\alpha = -10 \log_{10} \left(\frac{\lambda}{4\pi D}\right)^2$$

Since $-10 \log (x) = 10 \log (1/x)$, it follows that

$$\alpha = 10 \log_{10} \left(\frac{4\pi D}{\lambda}\right)^2$$

This relationship allows us to predict free-space path loss at any frequency, over any line-of-sight distance, as long as we measure distance and wavelength in the same units. It is certainly easier to employ than the various nomographs provided for that purpose in the literature, and is far easier to remember than those published equations that contain fudge factors to compensate for distance expressed in, say, miles, and wavelength in inches. Furthermore, if you understand the meaning of the decibel (and you should by now), the above equation should allow you to visualize the relationship in a physical sense.

Effective Isotropic Radiated Power

Moonbouncers use EIRP a lot. This is total output punch, measured in dBm. Think of it as a measure of the goo you have going out, in dB relative to a 1-milliwatt transmitter, connected through a lossless transmission line to an ideal isotropic antenna.

EIRP is calculated by adding together transmitter output power in dBm, feed-line loss in *negative* dB and antenna gain in dBi. Thus, a transmitter output of +40 dBm, applied through a 6-dB lossy transmission line to an antenna whose gain is +10 dBi, will generate an effective isotropic radiated power of (+40 dBm) + (−6 dB) + (+10 dBi) = +44 dBm.

It bothers some that we can mix such obviously diverse units as dB, dBi and dBm, but in each case, we are comparing a particular signal level to a *specified* reference. Only the reference changes for each element analyzed; the units of measure, dB (10 times the log of a power ratio) remains consistent throughout the calculation. Note that the transmitter output in the above example is 40 dB more than a milliwatt, the feed-line gain is 6 dB less than a lossless transmission line, and the antenna gain is 10 dB more than that of an isotrope. The resulting EIRP is then a power level, measured in dB relative to a specified (though perhaps elusive) reference power, or 44 dB more than the power radiated in a given direction, if 1 milliwatt were applied through a lossless transmission line directly to an isotropic antenna.

Actually, we mix units in other fields of endeavor with minimal confusion. Consider the technician earning $12 an hour, who receives a 10% raise. What is his new hourly salary? If you've been paying close attention, you might be tempted to say, "Wait a minute. You can't mix percents with dollars!" But of course you can. The final unit of measure will still be *dollars*. Percent simply signifies a *change*. Similarly, a power level in dBm (or dBW) can be thought of as an absolute level, like a wage in dollars. Cable loss in dB, path loss in dB, antenna gain in dBi (or dBd) and amplifier gain in dB all represent changes to the original signal level, much as a 10% raise represents a change in salary. The resulting power level, after all these changes have been accomplished, is of course measured in the original unit, dBm or dBW.

Receiver Sensitivity

A previously published article defines the major factors affecting receiver sensitivity.[8] Here we shall concern ourselves with how receiver sensitivity can be measured in dB.

In the absence of interference, any signal applied to the input of a receiver is competing with noise. For a signal to be heard, its power must exceed the total noise power by a specified amount (called signal-to-noise ratio) that varies as a function of modulation type, modulation percentage, signal conditioning, any special coding on the signal and the type of detector circuitry employed. Given the required signal-to-noise ratio, the receiver sensitivity is limited by the amount of noise power the signal has to override.

The noise power present at the input of a theoretically perfect receiver (that is, one which generates in its circuitry no additional noise above that occurring naturally in the environment) is a function of heat and bandwidth. Mathemagically,

$$Pn = kTB$$

where

Pn represents noise power in watts
k is Boltzmann's Constant (1.38×10^{-23} joules per kelvin)
T is the temperature of the receiver circuitry, in degrees absolute (or kelvins)
B represents the narrowest bandwidth (typically the IF bandwidth) of the circuitry preceding the detector stage, in Hz.

Since noise power can be calculated in watts, we can further convert it to milliwatts (simply multiply by 1000) and express it in decibels compared to a milliwatt, or dBm.

Consider the sensitivity of an ideal, noiseless receiver with a bandwidth of 1 Hz, operating at a temperature of 290 K (an accepted standard temperature for earth-based equipment). The resulting noise power with which any signal would have to compete will equal:

$$Pn = kTB$$
$$= (1.38 \times 10^{-23} \text{ joules/K}) \times (290 \text{ K}) \times (1 \text{ Hz})$$
$$= 4 \times 10^{-21} \text{ watts}$$
$$= 4 \times 10^{-18} \text{ mW}$$
$$= -174 \text{ dBm}$$

You may have read that the noise threshold (that is, the sensitivity at unity signal-to-noise ratio) of an ideal, noiseless receiver is −174 dBm per Hz of bandwidth, and you can see where this figure came from—except for one thing. The above value holds *only* at the so-called standard temperature of 290 K. The same receiver in the cold depths of space will experience significantly less thermal noise, and thus will exhibit higher sensitivity than the "−174 dBm/Hz" approximation would indicate.

Until now we have been talking about an ideal, noiseless receiver. In truth, the receiver circuitry itself is going to contribute some noise to its own input; thus the actual sensitivity of any receiver will be less than we have predicted by kTB. We can quantify the noise contribution of the receiver circuitry (and its resulting impact on sensitivity) in three different ways: noise factor, noise figure or noise temperature.

Noise factor (often abbreviated F) is a measure of the degree to which the receiver's internal noise increases the noise power, kTB. It represents a power ratio. Thus, if kTB, in watts or milliwatts, is

known, multiplying it by noise factor yields the actual noise power level which the applied signal must override. In the preceding example of a receiver with a 1-Hz bandwidth operating at standard temperature, a receiver noise factor of 2 would raise the actual noise threshold to:

$$\begin{aligned} Pn &= F \times (kTB) \\ &= 2 \times (4 \times 10^{-18}\ mW) \\ &= 8 \times 10^{-18}\ mW \\ &= -171\ dBm \end{aligned}$$

Noise figure (usually abbreviated NF) is simply noise factor expressed in dB. Since noise factor is a power ratio, we can convert it to dB by multiplying its common log by 10. To find a receiver's noise threshold when NF is known, simply add NF (in dB) to the dBm equivalent of kTB, that is, 10 times the common log of (kTB × 1000).

In the previous example, NF = $10 \log_{10} 2 = 3$ dB. Thus, the actual noise threshold was:

$$\begin{aligned} Pn &= 10 \log_{10} (kTB \times 1000) + NF \\ &= (-174\ dBm) + (3\ dB) \\ &= -171\ dBm \end{aligned}$$

You can see from this calculation that the 3-dB NF effectively degraded the sensitivity of our sample receiver by exactly 3 dB.

If a receiver's internal noise is expressed in noise temperature, we know that the equivalent thermal noise to which the receiver is subject exceeds its physical temperature by a specified amount. To find a receiver's noise threshold when noise temperature (sometimes called T_{eq}) is known, simply *add* noise temperature to 290 K (or whatever other physical temperature may apply) and utilize this sum when calculating noise power from kTB.

If noise temperature equals 290 K (equivalent to a 3-dB noise figure, or a noise factor of 2) and the receiver is operated at standard temperature, then the receiver's noise threshold is:

$$\begin{aligned} Pn &= k \times (290 + T_{eq}) \times B \\ &= k \times (290 + 290) \times B \\ &= 8 \times 10^{-18}\ mW \\ &= -171\ dBm \end{aligned}$$

The preceding three examples illustrate that when calculating receiver sensitivity, whether employing noise factor, noise figure or noise temperature, proper use of the decibel yields consistent results.

Link Analysis

Link analysis, perhaps the most elegant application of decibel calculations in electronic communications, allows us to quantify all of the elements of a communications system and predict its success. It combines all of the foregoing examples, in an attempt to predict the overall performance of a communications link. It is also the one application of decibels least favored by the Amateur Radio community.

The true ham, so legend has it, shuns any calculation that might dissuade him from any desired endeavor. After all, it is through analysis that the engineering community has determined that this or that objective is impossible, and thus expends no effort toward achieving it. The ham, it is argued, by not knowing that something is impossible, simply sets about accomplishing it ... and frequently succeeds.

The argument is certainly appealing. If you want to know how far you can communicate with a particular combination of equipment and conditions, the time-honored method is to point your antenna and call CQ. Who ever bothered to calculate EIRP, path loss, receiver sensitivity and required signal-to-noise ratio before getting on the air?

Yet there are applications where the analytical approach does make sense. Consider the world of communications satellites, where countless thousands of hours and hundreds of thousands of dollars may be expended in preparing a payload for orbit. There is certainly an advantage to making our OSCARs accessible to the greatest number of experimenters, and this can be assured by predicting, in advance of a launch, the precise user equipment necessary to access the satellite. If we wait until after a spacecraft achieves orbit, only to discover that its transponder is not accessible to stations operating within legal amateur power limits, we have done the user community a disservice.

Link analysis can be performed through multiplication of power ratios, that is, by multiplying transmitter power by antenna gain by path loss by receiving-antenna gain by required signal-to-noise ratio, and comparing the resulting power level to the receiver noise threshold, kTB. But this becomes awkward in the extreme. A far better approach might be to add logarithms. After all, isn't that why they were developed in the first place?

If we express transmitter power in dBm, transmitting-antenna gain in dBi, path loss in dB and receiving-antenna gain in dBi, the sum of these four quantities (less any feed-line losses along the way, in dB) will give us an accurate picture of the power level, in dBm, available to the distant receiver. We can compare this figure to the receiver sensitivity, in dBm, found from k, T, B, required signal-to-noise ratio and noise figure, and discern the available signal margin in the link, in dB. If this figure happens to be negative, we can explore various ways of improving link performance, before investing significant resources in what might otherwise prove a fruitless effort.

Of course, there will always be times when simply pointing the antenna and calling CQ is the appropriate way to quantify a communications path. But when prior knowledge of performance is required, proper use of the decibel can make the mathematics almost painless.

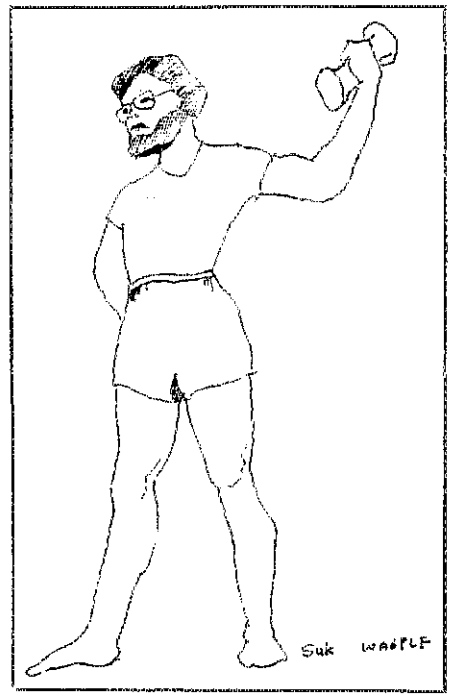


Fig. 2—The author lifting one Db (see text). *(drawing by WA6PLF)*

More Creative Misapplications

Gruchalla has cited a number of examples of creative misapplication of the decibel.[9] His powerful presentation bears some amplification, if we are to gain a full misunderstanding. Recognizing that using decibels is a way of expressing power ratios, consider the following case studies.

Case 1: Finance

A gallium-pesticide transistor delivers 12 dB of gain in a particular application and costs $9. A GLASSFET delivers 16 dB of gain in the same circuit and sells for $18. Which active device is the more cost effective?

The hollow-state device delivers a 4-dB gain advantage, at twice the unit cost. Ten times the common log of (twice the cost) equals 3 dB. Thus, the latter device delivers 4 dB of additional performance for 3 dB more dollars, for a net cost vs performance advantage of 1 dB. And the analysis is easily justifiable on the obvious basis, confirmed by countless economists, that money is power.

Case 2: Time Management

An engineer toils from 9 AM to 6 PM. Can you express his workday in dB? Let dB equal 10 times the common log of (time out over time in). Dividing 1800 hours by 0900 hours, and solving the above relationship, yields a 3-dB work day.

Except that the engineer takes an hour off for pretzels and bridge. Dividing 1300 hours by 1200 hours, we find that the

employee has enjoyed a 0.35-dB lunch hour, and thus should be paid for only 2.65 dB of labor.

The proof of the above relationship derives from a simple syllogism. Since time is money (just ask any busy executive), and money is power (see Case 1 above), and power is measured in dB, time can be measured in dB. If you don't understand this completely, come back in 10 dB and I'll explain it again.

Case 3: Athletics

You may recall our discussion about proper capitalization in Part 1. Fig 2 depicts an athlete lifting 1 Db.

During the Los Angeles Olympics, a weightlifter from West Hernia beat the world's record in his event by 0.6 dB. This figure was found in the usual way, by first dividing the weight he lifted by the previous record, then taking 10 times the log. And of course, dB is the appropriate unit, since the West Hernian was a power lifter.

Case 4: Municipal Planning

The mayor of the booming metropolis of Hictown (pop 37) comes to the startling discovery that not a single radio amateur resides within his jurisdiction. Upon researching the matter, he attributes this phenomenon to an obscure law, one that has been on the books since colonial times, prohibiting "the erection of any flagpole, standard, mast or similar structure, which exceeds the height of the Giant Sycamore gracing the town square." Said sycamore was struck by lightning in the Great Storm of '08, with only a gnarled stump remaining. Hence, all antennas but TV rabbit ears are prohibited.

Recognizing the many public service benefits of ham radio, this astute leader promptly and permanently rescinds all antenna ordinances. Obviously, Hictown soon becomes a mecca for our brethren, who immigrate in significant numbers, erect impressive towers, swell the population to 138,214 and change the name of their town to Antlerville.

What, you may ask, was the population gain in dB in the above example? Ten times the common log of the ratio (population now over population then) equals 35.7 dB, but is this a valid application of the dB? It is if you, as I, were a college student during the turbulent '60s, when the watchword was "Power to the People!"

Case 5: Literature

This last example will constitute your homework assignment; please complete the analysis and turn it in at the beginning of the next class period. You are asked to assess the extent to which this article has expanded the available literature in the area of dB analysis. Count the number of words in both parts of this article, as well as those in Gruchalla's paper (Ref 9). The number of dB by which this paper increases human knowledge can be estimated as 10 times the common log of the quantity (words here) divided by the sum (words here plus words elsewhere).

Why is dB notation appropriate here? It was Thomas Hobbes who wrote, "Knowledge is Power." Furthermore I remind you, as is mentioned every month in *Reader's Digest,* "It Pays to Enrich Your Word Power."

Notes and References

[6]The sun's radiation pattern comes close, but remember that the sun is not perfectly spherical. Because of its rotation on its axis, the sun is oblate, like the earth (that is, fatter around the equator than at the poles). Since the sun's radiation pattern is closely correlated to its shape, the sun cannot be a perfect isotropic radiator. Neither is any physically realizable antenna.

[7]For meaningful measurements to result, the antenna under test must be evaluated at *far-field*—that is, at a measurement distance which is very great, relative to both wavelength and antenna aperture.

[8]J. R. Fisk, "Receiver Sensitivity, Noise Figure and Dynamic Range—What the Numbers Mean," *Ham Radio,* Oct 1975, p 8. This article, penned 10 years ago by the late W1HR, represents *the* definitive work on the subject of receiver performance. I consider it to be one of those landmark papers that should be reviewed (and hopefully reprinted) periodically.

[9]M. Gruchalla, "Defining the Decibel," *Ham Radio,* Feb 1985, p 51.

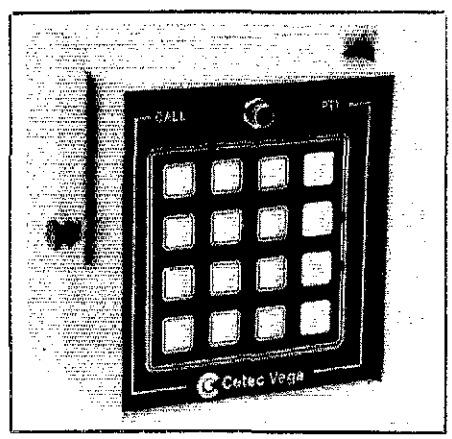
New Products

CETEC VEGA MODEL ED-707 MOBILE DTMF ENCODER/DECODER

☐ Cetec Vega's new Model ED-707 dual-tone, multifrequency (DTMF) mobile encoder/decoder is designed for tough service. It has a comprehensive set of operational features, including: (1) selective, group, and all call (2- to 6-digit messages); (2) single-tone transpond; (3) full DIP-switch programmability; (4) command reset; (5) audible encode sidetone; (6) fully sealed keypad with 12 DTMF digits as well as horn, speaker, and "T" switch; and (7) wrong-digit reset or wrong-digit lockout (jumper selectable).

Construction features include: (1) rugged aircraft-alloy case; (2) fully sealed DTMF/control switch keypad; (3) water-tight Neoprene™ panel gasket; and (4) stainless-steel fasteners.

The unit provides a resistive load for the radio's single-ended audio output or bridge-output power amplifiers when the speaker is switched off through the ED-707, as well as adjustable timers for sounder/horn, tone-burst transpond, off delay, PTT delay and interdigit time. For additional information contact Cetec Vega, 9900 Baldwin Pl, El Monte, CA 91731, tel 818-442-0782. —*Bruce O. Williams, WA6IVC*



Next Month in *QST*

Several construction and tutorial articles await you in April *QST.* Among them is an article on SuperSCAF and Son—a team of switched-capacitor audio filters that can't be beat, and Part 1 of a four-part series on OSCAR operation. The first installment introduces you to some basic satellite terminology and concepts. And no April issue would be complete without a variety of antenna projects. Having trouble meeting the code requirements for that Extra Class ticket? Check out the article on one ham's system for cracking the 20-WPM barrier. Also, if contests are your thing, you won't want to miss the results from the 160-Meter and EME contests and Straight Key Night, and the rules for the Great Armadillo Run.